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Fabrication of a Set of Realistic Torso Phantoms for Calibration of Transuranic Nuclide Lung Counting Facilities

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Fabrication of a Set of Realistic Torso Phantoms for Calibration of Transuranic Nuclide Lung Counting Facilities*

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The calibration of whole body counters for accurate measurement of transuranic nuclides deposited in the lungs requires highly realistic phantoms. The realism includes faithful simulation, not only of the torso and organ morphology, but the composition of appropriate tissues--muscle, bone, adipose, cartilage and lung. Recognizing this fact, the U. S. Department of Energy supported fabrication of three tissue equivalent torso phantoms to be used in an interlaboratory intercomparison program.[1] The phantoms included a human rib cage and removable tissue equivalent lungs, heart, liver and lymph nodes. The tissue equivalent materials, including the foamed lungs, are based on a polyurethane-calcium carbonate composition.[2] Only the rib cage was real tissue.

As the intercomparison program proceeded, it became clear that each of the laboratories involved required the use of the phantoms for longer periods of time than the program schedule allowed. In fact, a number of laboratories expressed interest in having phantoms that could be used as permanent parts of their individual calibration programs. Therefore, we agreed to fabricate a second set of phantoms for each of the laboratories on a cost recovery basis. As a result, 16 phantoms were made for laboratories in England, Canada, the United States and the International Atomic Energy Agency.

The new phantoms were identical to the original three, with the exception that a simulated rib cage would replace the real bone used in the original phantoms. This required development of a bone equivalent material for the ribs and backbone. The ribs are structurally complex with a solid outer layer and a trabecular core of fine bone and marrow. Therefore, choice of a single reference tissue for simulation is not obvious. However, we selected the "rib bone" composition proposed by White[3] as our reference tissue.

Molds existed from the original phantoms for the torso, chest plates and interior organs. The simulated bones for the replica phantoms are made using casts of the real rib cage incorporated in the third of the original phantom set. Following casting, the plastic rib cage is assembled on a plaster torso cavity mandrel (Fig. 1). The mandrels are cast with fine grooves indicating the proper placement of each bone. The torso is cast with the mandrel in place. The mandrel is removed destructively, after the torso has cured and the cut is made for removal of the chest plate (Fig. 2). The organs and chest overlays are cast using conventional casting techniques.[1] With the exception of the bones, lungs and cartilage segments used to join ribs to the sternum, all organs have a muscle equivalent composition. The chest overlays have been made to simulate one of three different chest wall compositions: 100% muscle; 50% muscle, 50% adipose (breast); or 13% muscle, 87% adipose. Table 1 presents the simulant composition summary.

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Fig. 1. Plaster mandrel of torso interior with simulated bone rib cage in place.

Table 1. Composition of Tissue Simulants Used in Realistic Phantoms

	Elemental Composition - Wt %[1]				
Tissue	H	C	N	O	Ca
Muscle	9.00	61.9	2.98	24.4	1.72
50% Adipose-50% Muscle	9.23	63.0	3.03	23.9	0.84
87% Adipose-13% Muscle	9.46	64.1	3.14	23.3	0.00
Cartilage	8.89	61.1	2.98	24.7	2.33
Bone	6.38	47.2	2.12	31.3	13.0
Lung	8.91	61.6	2.95	24.3	2.24

[1]Nominal composition. Actual composition may vary slightly due to variations in commercial polyurethane supply.

Reproducibility is an important aspect in the use of the realistic phantoms. Moreover, the value of the phantom set is enhanced significantly if there is a precise method of intercomparing results obtained with different phantoms in the series. Therefore, we adopted a marking system for the front surface of the phantoms and each of the chest overlays. The most important positions for external detector measurement are centered over each lung and the liver. A pattern of concentric circles extending, in one-inch increments, to five inches in diameter was applied to the phantom and overlay surfaces at these three positions. In addition, we used a coordinate pattern with 2 cm

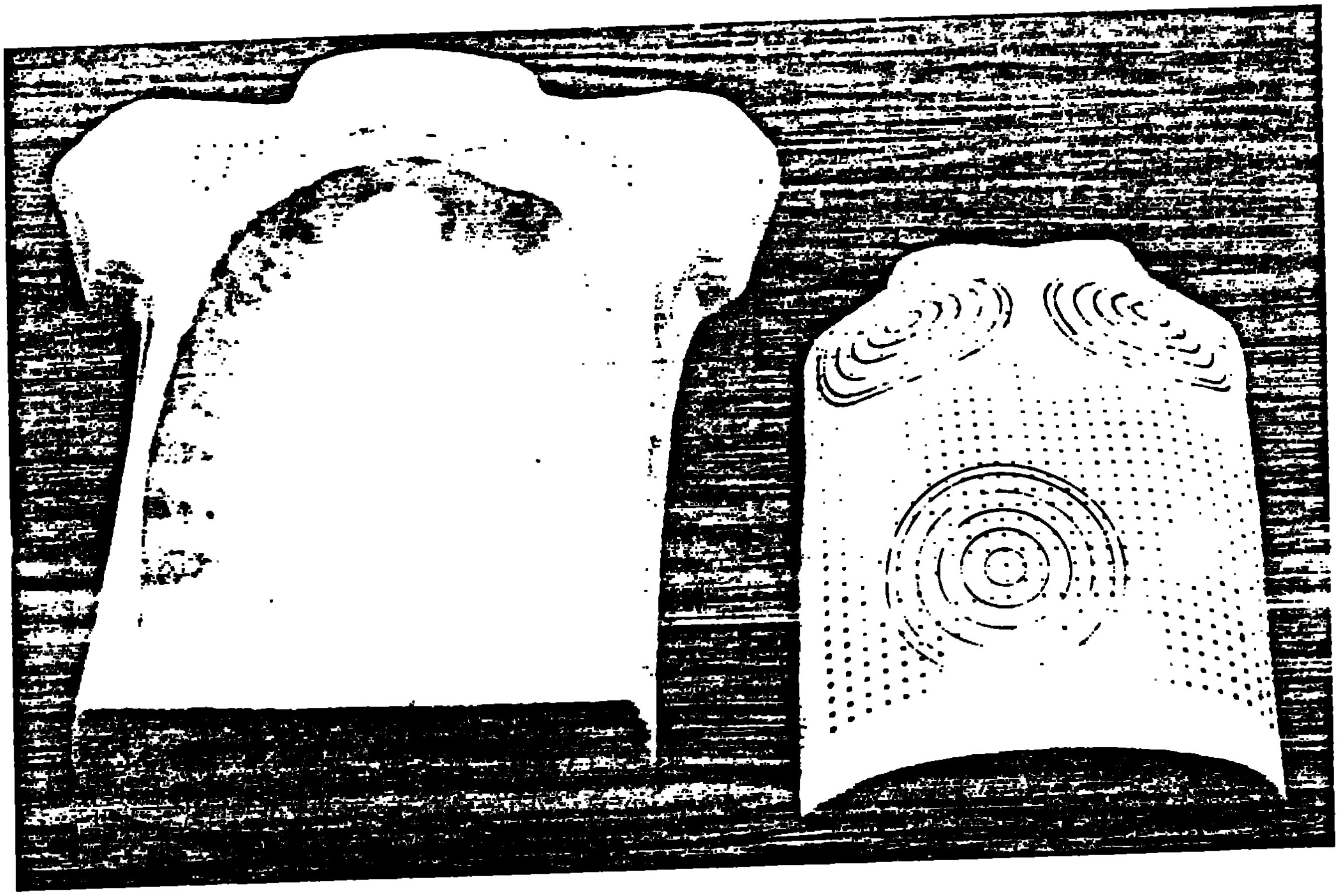

Fig. 2. Torso with chest plate removed.

grid spacing projected on the same surfaces. The patterns have an alpha-numeric labelling system that gives each coordinate intersection a unique identification referencable on any other phantom or chest overlay.

The primary goal of the fabrication of the new phantom set was duplication of the original phantoms as closely as possible. A major concern was the effect of the simulated bone rib cage on transmission of low energy photons such as the 17 keV uranium X-rays from plutonium decay. Therefore, we performed measurements using lungs loaded with ^{238}Pu both in the original phantoms and phantoms selected from the new series. The results of the comparison are illustrated in Fig. 3. The new phantoms have chest walls that are thinner than the original set by about 4 mm. However, the new phantoms match the performance of the originals closely, and the duplication is considered successful.

Summary

A set of 16 tissue equivalent torso phantoms has been fabricated for use by major laboratories involved in counting transuranic nuclides in the lung. These phantoms, which have bone equivalent plastic rib cages, duplicate the performance of the DOE Realistic Phantom set. The new phantoms (and their successors) provides the user laboratories with a highly realistic calibration tool. Moreover, use of these phantoms will allow participating laboratories to intercompare calibration information, both on formal and informal bases.

References

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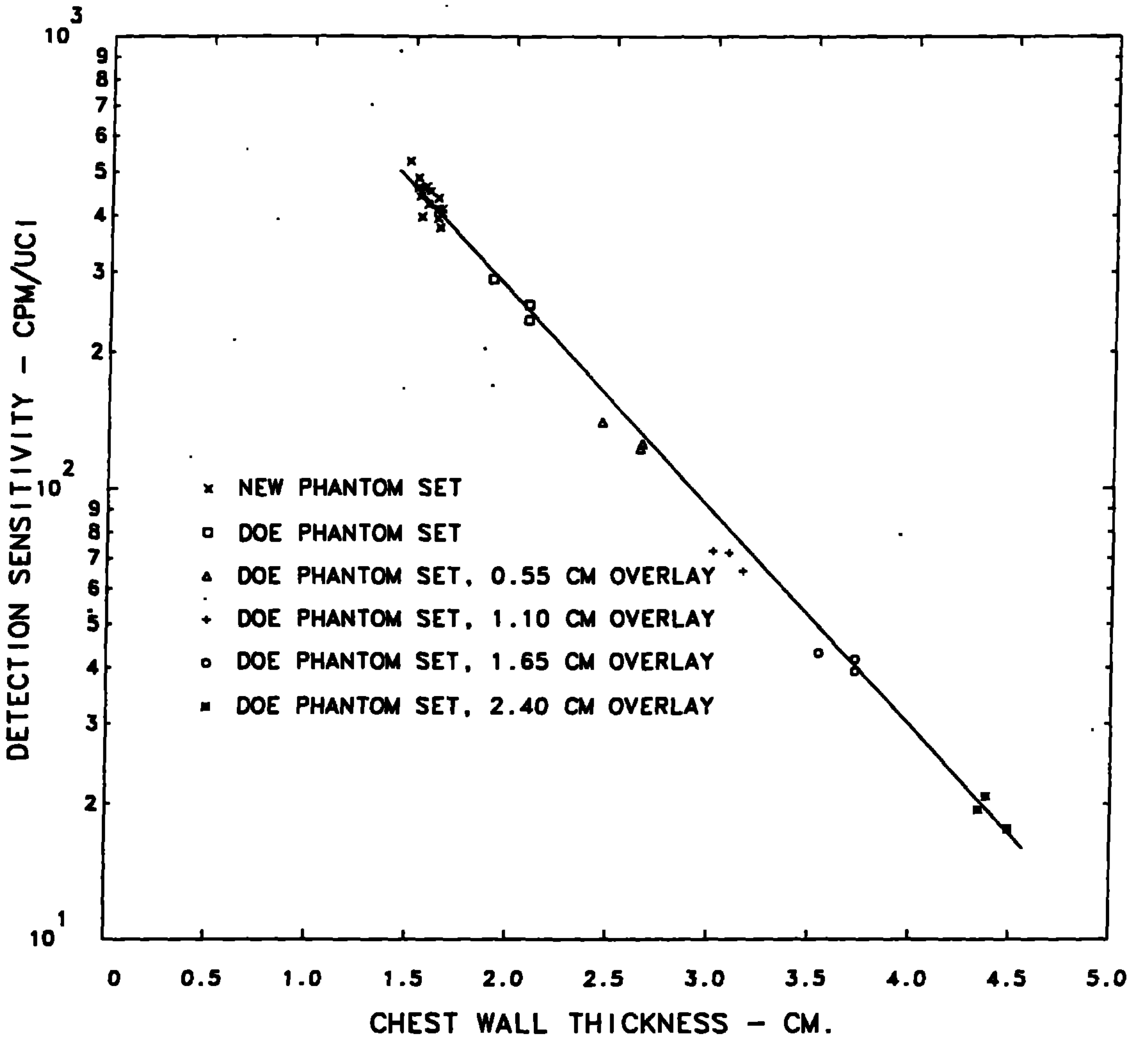

Fig. 3. ^{238}Pu calibration factors for realistic phantoms using dual 4.5 inch diameter phoswich lung counters.

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2. Griffith R.V. (1980), "Polyurethane as a Family of Tissue Equivalent Materials," Proc. 5th International Congress of the International Radiation Protection Association, Vol. II, 165-168, Jerusalem.

3. Newton D. and White D.R. (1978), "Attenuation of 13-20 keV Photons in Tissue Substitutes and Their Validity for Calibration Purposes in the Assessment of Plutonium in Lungs," Health Physics, 35, No. 65, 699-703.